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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	35.G2661
First Named Inventor or Application Identifier	
YOSHINORI ITO	
Express Mail Label No.	

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

ADDRESS TO: Commissioner for Patents
Box Patent Application
Washington, DC 20231

1. [X] Fee Transmittal Form
(Submit an original, and a duplicate for fee processing)

2. [ ] Applicant claims small entity status.
See 37 CFR 1.27.

3. [X] Specification — *Total Pages* 31

4. [X] Drawing(s) *(35 USC 113)* — *Total Sheets* 13

5. [ ] Oath or Declaration — *Total Pages*

   a. [ ] Newly executed (original or copy)

   b. [ ] Copy from a prior application (37 CFR 1.63(d))
   (for continuation/divisional with Box 17 completed)
   [Note Box 6 below]

   i. [ ] DELETION OF INVENTOR(S)
   Signed Statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b).

6. [X] Application Data Sheet. See 37 CFR 1.76

7. [ ] CD-ROM or CD-R in duplicate, large table or Computer Program *(Appendix)*

8. [ ] Nucleotide and/or Amino Acid Sequence Submission
(if applicable, all necessary)

   a. [ ] Computer Readable Form (CRF)

   b. Specification Sequence Listing on:

      i. [ ] CD-ROM or CD-R (2 copies); or

      ii. [ ] paper

   c. [ ] Statements verifying identity of above copies

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ACCOMPANYING APPLICATION PARTS

9. [ ] Assignment Papers (cover sheet & document(s))

10. [ ] 37 CFR 3.73(b) Statement *(when there is an assignee)* [ ] Power of Attorney

11. [ ] English Translation Document *(if applicable)*

12. [X] Information Disclosure Statement (IDS)/PTO-1449 [X] Copies of IDS Citations

13. [ ] Preliminary Amendment

14. [X] Return Receipt Postcard (MPEP 503)
(Should be specifically itemized)

15. [ ] Certified Copy of Priority Document(s)
(if foreign priority is claimed)

16. [ ] Other: _____

17. If a CONTINUING APPLICATION, *check appropriate box and supply the requisite information:*

[ ] Continuation [ ] Divisional [ ] Continuation-in-part (CIP) of prior application No. __/_____

Prior application information: *Examiner* _____ *Group/Art Unit:* _____

For CONTINUATION OR DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 5b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

18. CORRESPONDENCE ADDRESS

[X] Customer Number or Bar Code Label — 05514 (~~Insert Customer No. or Attach bar code label here~~) or [ ] Correspondence address below

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CLAIMS	(1) FOR	(2) NUMBER FILED	(3) NUMBER EXTRA	(4) RATE	(5) CALCULATIONS
	TOTAL CLAIMS (37 CFR 1.16(c))	12-20 =	0	X $ 18.00 =	$ 0.00
	INDEPENDENT CLAIMS (37 CFR 1.16(b))	2-3 =	0	X $ 80.00 =	$ 0.00
	MULTIPLE DEPENDENT CLAIMS (if applicable) (37 CFR 1.16(d))			$270.00 =	$ 0.00
				BASIC FEE (37 CFR 1.16(a))	$ 710.00
			Total of above Calculations =		$ 710.00
	Reduction by 50% for filing by small entity (Note 37 CFR 1.9, 1.27, 1.28).				
				TOTAL =	$ 710.00

19. Small entity status

a. ☐ A small entity statement is enclosed

b. ☐ A small entity statement was filed in the prior nonprovisional application and such status is still proper and desired.

c. ☐ Is no longer claimed.

20. ☒ A check in the amount of $ 710.00 to cover the filing fee is enclosed.

21. ☐ A check in the amount of $ _____ to cover the recordal fee is enclosed.

22. The Commissioner is hereby authorized to credit overpayments or charge the following fees to Deposit Account No. 06-1205:

a. ☒ Fees required under 37 CFR 1.16.

b ☐ Fees required under 37 CFR 1.17.

c. ☐ Fees required under 37 CFR 1.18.

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT REQUIRED	
NAME	Gary M. Jacobs - Reg. No. 28,861
SIGNATURE	
DATE	October 18, 2000

DSG\GMJ\cmv

TITLE OF THE INVENTION

ZOOM LENS AND OPTICAL APPARATUS

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a zoom lens and an optical device incorporating the zoom lens, and, more specifically, to a rear-focus zoom lens having a high zoom ratio with a relatively small number of lens elements, appropriate for use in a video camera, a film camera, a broadcast camera, and to an optical apparatus incorporating the zoom lens.

Description of the Related Art

Various rear-focus zoom lenses, which perform focusing by moving a lens unit behind a first lens unit closer to an object, have been proposed as zoom lenses used in film cameras or video cameras. Since the rear focus method moves a relatively compact and light-weight lens unit during focusing, the driving power required is small, and the focusing operation through the rear focus method is rapid enough to work compatibly with an auto-focusing system.

For instance, Japanese Patent Laid-Open No. 63-44614 discloses a so-called four-group rear-focus zoom lens which

includes, in the order from the object end, a first lens unit having positive refractive power, a second lens unit for zooming having negative refractive power, a third lens unit having negative refractive power for correcting the shift of an image plane in response to zooming, and a fourth lens unit having positive refractive power. The focusing operation is performed by moving the third lens unit. The arrangement requires the space within which the third lens unit travels, and the overall length of the lens system increases.

Japanese Patent Laid-Open No. 63-278013 discloses a four-group rear-focus zoom lens which includes a first lens unit having positive refractive power, a second lens unit having negative refractive power, a third lens unit having negative refractive power, and a fourth lens unit having positive refractive power. The second lens unit effects zooming, and the fourth lens unit performs image plane correction and focusing. In the zooming method using the third lens unit having negative refractive power, diverging light rays from the second lens unit further diverge through the third lens unit. The lens diameter of the fourth lens unit increases, leading to a bulky design. Furthermore, a variation in aberration due to focusing becomes large.

Each of Japanese Patent Laid-Open No. 62-24213 and Japanese Patent Laid-Open No. 63-247316 discloses a four-

group zoom lens which includes, in the order from the object end, a first lens unit having positive refractive power, a second lens unit having negative refractive power, a third lens unit having positive refractive power, and a fourth lens unit having positive refractive power. The second lens unit is moved for zooming, and the fourth lens unit is moved to correct an image plane shift arising from zooming, while effecting focusing. Compact design is thus implemented in the overall lens system.

Japanese Patent Laid-Open No. 63-29718 discloses a four-group zoom lens which includes, in the order from the object end, a first lens unit having positive refractive power, a second lens unit, composed of three lens elements of a negative lens, a negative lens and a positive lens, and generally having negative refractive power and movable for zooming, a third negative lens having negative refractive power and having an aspherical surface, and a fourth lens unit, having positive refractive power and a relatively wide air gap therewithin. The fourth lens unit corrects an image plane shift arising from zooming, while moving for focusing.

Japanese Patent Laid-Open No. 5-72472 discloses a four-group zoom lens which employs aspherical surfaces and includes, in the order from the object end, a first lens unit having positive refractive power and remaining stationary during zooming and focusing, a second lens unit

having negative refractive power and movable for zooming, a third lens unit remaining stationary and having a light converging effect with positive refractive power, and a fourth lens unit having positive refractive power and axially movable along an optical axis to keep the image plane position fixed against movements in response to zooming. In the zoom lens disclosed, the second lens unit is composed of a negative meniscus lens, a negative bi-concave lens, and a positive lens, the third lens unit is composed of a single lens element having at least one aspherical surface, and the fourth lens unit is composed of a lens having at least one aspherical surface.

In the above-referenced six disclosures, there is no mention of a zoom lens having the second lens unit composed of four lenses.

United States Patent No. 4,299,454 discloses a zoom lens which includes, in the order from the object end, a first lens unit having positive refractive power, a second negative lens unit, and a rear positive lens unit. Two lenses including at least the second negative lens unit are movable to effect zooming. The second negative lens unit is composed of first and second negative lenses and a positive doublet from the object end. Since the third lens unit moves, the mechanism of the zoom lens become complicated. United States Reissue Patent No. RE32,923 discloses a zoom

lens which includes, in the order from the object end, a first positive lens unit, a second negative lens unit, a diaphragm, a third positive lens unit, and a fourth positive lens unit. The first and fourth lens units move in the same direction during zooming, and the diaphragm remains stationary during the zooming. The second lens unit employs a single cemented lens.

In the two United States Patents No. 4,299,454 and RE32,923, there is no mention of the third lens unit which has aspherical surfaces on both sides thereof.

Each of Japanese Patent Laid-Open No. 7-270684 and Japanese Patent Laid-Open No. 7-318804 discloses a zoom lens which includes, in the order from the object end, a first lens unit remaining stationary and having positive refractive power, a second lens unit having negative refractive power, for zooming, a third lens unit remaining stationary and having positive refractive power, and a fourth lens unit having positive refractive power and axially movable in the optical axis for keeping the image plane fixed in position against zooming, and for focusing. The second lens unit is composed of four lens elements. In these disclosures, there is no mention of the third lens unit which has aspherical surfaces on the two sides thereof.

Japanese Patent Laid-Open No. 5-060974 discloses a short overall-lens-length zoom lens which includes, in the

order from the object end, a first lens unit remaining stationary and having positive refractive power, a second lens unit, having negative refractive power, for zooming, a third lens unit remaining stationary and having positive refractive power, and a fourth lens unit having positive refractive power and axially movable along the optical axis to keep the image plane fixed in position against zooming and to perform focusing. There is neither mention of the second lens unit being composed of four single lens elements nor mention of the third lens unit having aspherical surfaces on the two sides thereof.

The implementation of the rear focus method in the zoom lens typically makes the design of the lens system compact, and permits focusing to be quickly performed, and close-up photographing is easily performed.

On the other hand, variations in aberration during focusing increase, and it is difficult to achieve high optical performance over an object range covering from infinity to a near object.

In particular, it is very difficult to maintain high optical performance over the object range within an overall zoom range with a simplified construction of a zoom lens having a large zoom ratio and a high aperture ratio.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a zoom lens which has high optical performance for a high zoom ratio thereof, and features compact design with a short overall lens length and a simple construction with a reduced number of lens elements, and to provide an optical apparatus incorporating the zoom lens.

It is another object of the present invention to provide a zoom lens which has high optical performance, permitting quick focusing, and suffering from less variation in aberration during focusing.

In one aspect, a zoom lens of the present invention includes, in the order from the object end thereof, a first lens unit having positive refractive power, a second lens unit having negative refractive power and being movable during zooming, and consisting of four single lenses, separated one from another, three of these lenses each having negative refractive power, and one lens having positive refractive power, a third lens unit, having positive refractive power, including at least one lens having positive refractive power and having aspherical surfaces on the two sides thereof, and a fourth lens unit having positive refractive power and being movable during zooming.

In a preferred embodiment, the first lens unit includes,

in a position close to the object, a first lens having negative refractive power, a second lens having positive refractive power, and a third lens having positive refractive power, and wherein the condition equation of $1.72 < (n12 + n13)/2 < 1.77$ holds where n12 represents the index of refraction of the second lens and n13 represents the index of refraction of the third lens.

In a preferred embodiment, the second lens unit includes a first lens having negative refractive power at the object end thereof, and wherein the condition equation of $0.04 < R21r/ft < 0.07$ holds where R21r represents the radius of curvature of the first lens on the image side surface thereof and ft represents the focal length of the entire lens system at the telephoto end.

In a preferred embodiment, the second lens unit consists of four lenses having negative, negative, positive, and negative refractive power in the order from the object end thereof.

In a preferred embodiment, the second lens unit consists of, in the order from the object end thereof, a first lens having negative refractive power and having a concave image side surface, a second bi-concave lens having negative refractive power, a third lens element having positive refractive power and having a convex object side surface, and a fourth bi-concave lens having negative

refractive power.

In a preferred embodiment, the third lens unit consists of a first bi-convex lens having positive refractive power, and a second meniscus lens having negative refractive power and having a convex object side surface.

In a preferred embodiment, the fourth lens unit consists of two lenses, one having positive refractive power and one having negative refractive power.

In a preferred embodiment, the fourth lens unit includes a first bi-convex lens having positive refractive power, and a second meniscus lens unit having negative refractive power and having a convex image side surface.

In another aspect, an optical apparatus of the present invention includes a zoom lens which includes, in the order from the object end thereof, a first lens unit having positive refractive power, a second lens unit having negative refractive power and being movable during zooming, and consisting of four single lenses, separated one from another, three of these lenses each having negative refractive power, and one lens having positive refractive power, a third lens unit having positive refractive power including at least one lens having positive refractive power and having aspherical surfaces on the two sides thereof, and a fourth lens unit having positive refractive power and being movable during zooming, and a body for supporting the

zoom lens.

In a preferred embodiment of the optical apparatus, the first lens unit includes a first lens having negative refractive power, a second lens having positive refractive power, and a third lens having positive refractive power, and wherein the condition equation of $1.72 < (n12 + n13)/2 < 1.77$ holds where n12 represents the index of refraction of the second lens and n13 represents the index of refraction of the third lens.

These and further aspects and features of the invention will become apparent from the following detailed description of preferred embodiments thereof taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A-1C show sections of lenses of a first numerical example of the present invention;

FIG. 2A-2I are aberration charts of the first numerical example of the present invention at the wide-angle end;

FIG. 3A-3I are aberration charts of the first numerical example of the present invention at an intermediate point;

FIG. 4A-4I are aberration charts of the first numerical example of the present invention at the telephoto end;

FIGS. 5A-5C show sections of the lenses of a second

numerical example of the present invention;

FIGS. 6A-6I are aberration charts of the second numerical example of the present invention at the wide-angle end;

FIGS. 7A-7I are aberration charts of the second numerical example of the present invention at an intermediate point;

FIGS. 8A-8I are aberration charts of the second numerical example of the present invention at the telephoto end;

FIGS. 9A-9C show sections of the lenses of a third numerical example of the present invention;

FIGS. 10A-10I are aberration charts of the third numerical example of the present invention at the wide-angle end;

FIGS. 11A-11I are aberration charts of the third numerical example of the present invention at an intermediate point;

FIGS. 12A-12I are aberration charts of the third numerical example of the present invention at the telephoto end; and

FIG. 13 generally shows an optical apparatus of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. 1A-1C are sectional views showing a major portion of one embodiment of a picture-taking device having a rear-focus zoom lens of the present invention. The data of the rear-focus zoom lens is given later as a first numerical example. FIGS. 2A through 4I are aberration charts of the embodiment with the zoom position at the wide-angle end, an intermediate point, and the telephoto end.

FIGS. 5A-5C are sectional views showing a major portion of a picture-taking device having a rear-focus zoom lens of the present invention. The data of the rear-focus zoom lens is given later as a second numerical example. FIGS. 6A through 8I are aberration charts with the zoom position at the wide-angle end, an intermediate point, and the telephoto end.

FIGS. 9A-9C are sectional views showing a major portion of a picture-taking device having a rear-focus zoom lens of the present invention. The data of the rear-focus zoom lens is given later as a third numerical example. FIGS. 10A through 12I are aberration charts with the zoom position at the wide-angle end, an intermediate point, and the telephoto end. FIGS. 1A, 5A, and 9A respectively show the zoom position at the wide-angle end, FIGS. 1B, 5B, and 9B respectively show the zoom position at the intermediate point, and FIGS. 1C, 5C, and 9C respectively show the zoom

position at the telephoto end.

There are shown a first lens unit L1 having positive refractive power, a second lens unit L2 having negative refractive power, a third lens unit L3 having positive refractive power, and a fourth lens unit L4 having positive refractive power. An aperture diaphragm SP is arranged in front of the third lens unit L3, and a glass block G is a color separating prism, a face plate, or a filter. An image pickup device such as a CCD (Charged-Coupled Device) is arranged at an image plane IP.

In this embodiment, the second lens unit is moved from the wide-angle end to the telephoto end in a zooming operation while a shift of the image plane arising from the zooming operation is compensated for by moving the fourth lens unit in whole or in part (the whole fourth lens unit in this embodiment) in a locus convex toward the object.

Employed here is the rear focus method in which the fourth lens unit in whole or in part (the whole fourth lens unit in this embodiment) is axially moved to effect focusing. With the zoom lens focusing on infinity or a near object, a solid curve line 4a or a dotted curve line 4b respectively represents a locus of the fourth lens unit to compensate for the shift of the image plane resulting from the zooming operation from the wide-angle end to the telephoto end. The first and third lens units remain stationary during the

zooming or focusing operation.

The fourth lens unit is moved, compensating for the shift of the image plane involved in the zooming operation while concurrently effecting focusing. As represented by the curve lines 4a and 4b, the fourth lens unit is moved in loci convex toward the object in the zooming operation from the wide-angle end to the telephoto end. This arrangement utilizes effectively the space between the third lens unit and the fourth lens unit while shortening the overall physical length of the lens system.

When the focusing is performed from infinity to a near object at the telephoto end in the embodiment, the fourth lens unit is projected frontward as represented by line 4c.

The feature of the present invention lies in that the second lens unit L2 is composed of four single separate lenses, three negative and one positive, that the third lens unit L3 includes at least one lens element having aspherical surfaces on the two sides thereof, and that the indexes of refraction of the materials n12 and n13 of the positive lenses of the first lens unit satisfy condition equation (1).

$$1.72 < (n12 + n13)/2 < 1.77 \quad \ldots \quad (1)$$

In the zoom lens of the present invention, the second lens unit L2, greatly contributing to the zooming operation, is arranged as discussed above, thereby reducing the power budget shared among the lenses and reducing the Petzval sum.

This arrangement reduces the displacement of the image plane due to the zooming even with a high zoom ratio. Furthermore, optical performance is improved by arranging at least one lens having aspherical surfaces on the two sides thereof in the third lens unit L3 which receives a diverging light beam from the second lens unit L2. This arrangement eliminates the need for an aspherical surface in the fourth lens unit L4, thereby reducing costs. In this embodiment, the lens closest to the object has the aspherical surfaces on the two sides thereof in the third lens unit L3.

The first lens unit L1 includes, in the order from the object end, a negative eleventh lens, a positive twelfth lens, and a positive thirteenth lens. Indexes of refraction n12 and n13 of the materials of the twelfth lens and the thirteenth lens are set to satisfy condition equation (1), thereby making the radius of curvature of each lens less severe, and thinning the thickness of each lens. This leads to the shortening of the overall length of the lens system.

Condition equation (1) relates to the indexes of refraction of the materials of the positive lenses in the first lens unit L1. If the mean of the indexes of refraction becomes too high, exceeding the upper limit, the manufacturing of the lenses becomes difficult. The mean of the indexes of refraction being greater than the upper limit is thus not preferable. If the mean of the indexes of

refraction becomes too low, dropping below the lower limit, the radius of curvature of the lens surface becomes severe. To assure an edge thickness of the lens, the thickness of the lens must also be increased. This leads to an increase in the overall length of the lens system. The mean of the indexes of refraction being smaller than the lower limit is thus not preferable, either.

More preferably, the numerical range defined by condition equation (1) is modified as follows:

$$1.73 < (n12 + n13)/2 < 1.74 \quad \ldots \quad (1a)$$

In this embodiment, the lens system is arranged as discussed above, thereby assuring high optical performance over an overall zoom range and over an overall object range.

The zoom lens of the present invention that satisfies the above condition is thus manufactured. One of the following conditions is preferably satisfied to attain optical performance while maintaining the zoom ratio.

(A-1) The second lens unit L2 includes a twenty-first lens at the closest position thereof, and let R21r represent the radius of curvature of the lens image side surface of the twenty-first lens and ft represent the focal length of the entire system at the telephoto end, and the following condition equation (2) holds.

$$0.04 < R21r/ft < 0.07 \quad \ldots \quad (2)$$

In equation (2), the image side surface of the twenty-

first lens, which is closest to the object in the second lens unit, is normalized by the focal length at the telephoto end. If the curvature is milder than the upper limit defined by equation (2), it becomes difficult to correct coma flare in the wide-angle region. If the curvature becomes severe, dropping below the lower limit, the manufacturing of the lens becomes difficult.

The numerical range in equation (2) is preferably modified as follows:

$$0.055 < R21r/ft < 0.065 \quad \ldots (2a)$$

(A-2) The third lens unit L3 includes a positive thirty-first bi-convex lens, and a meniscus negative thirty-second lens having a convex object side surface.

(A-3) The second lens unit L2 includes four lenses of negative, negative, positive, and negative in the order from the object end thereof.

(A-4) The fourth lens unit L4 includes two lenses, one negative and one positive.

(A-5) The second lens unit L2 includes, in the order from the object end, a negative twenty-first lens having a strongly concave image side surface, a negative twenty-second bi-concave lens, a positive twenty-third lens having a convex object side surface, preferably strongly convex, and a negative twenty-fourth bi-concave lens.

(A-6) The fourth lens unit L4 includes a positive

forty-first bi-convex lens, and a meniscus negative forty-second lens having a convex image side surface.

The zoom lens of the present invention thus performs a quick zooming operation with fewer variations introduced in aberration during focusing, thereby attaining high optical performance.

The rear focus method allows compact design to be implemented in the entire lens system, thereby allowing the zoom lens to focus quickly. The construction of the first lens unit L1 is simple, because the first lens unit L1 remains stationary during the zooming. For its high zoom ratio of 20 or more, the zoom lens attains high optical performance. The lens count is small, and the overall length of the lens system is shortened.

A video camera (an optical apparatus), employing the zoom lens of the present invention as its image pickup optical system, is now discussed, referring to FIG. 13.

Referring to FIG. 13, there are shown a video camera 10, an image pickup optical system 11 composed of the zoom lens of the present invention, an image pickup device 12, such as a CCD, receiving the image of an object through the image pickup optical system 11, a recording unit 13 for recording the image received by the image pickup device 12, and a view finder 14 for observing the image of the object provided by a display device (not shown). The display device, composed

of a liquid-crystal panel, for instance, displays the image of the object formed on the image pickup device 12.

A compact optical apparatus having high optical performance is thus manufactured by incorporating the zoom lens of the present invention into an optical apparatus such as a video camera.

The first through third numerical examples of the lenses of the present invention are listed below.

In each numerical example, Ri represents the radius of curvature of an i-th surface from the object end, Di represents the gap between the i-th surface and an (i+1)-th surface from the object end, and Ni and νi respectively represent the index of refraction and the Abbe number of an i-th glass optical member from the object end.

The shape of the aspheric surface is expressed in the coordinates with the X axis in the optical axis and the H axis in a direction perpendicular to the optical axis, the direction of travel of light is taken as positive, R is the radius of the osculating sphere, and K, B, C, D, E, and F are the aspheric coefficients, and the following equation (3) holds.

$$X = \frac{(1/R)H^2}{1+\sqrt{1-(1+K)(H/R)^2}} + BH^4 + CH^6 + DH^8 + EH^{10} \quad \cdots \quad (3)$$

In the values of the aspheric coefficients, the notation "e-Z" means 10^{-z}.

The last three lens surfaces in the numerical examples are glass blocks such as a face plate or a filter. Table 1 lists the relationship between each of the condition equations and values in each of the numerical examples of the embodiment.

The First Numerical Example

f=3.70-83.21	Fno=1.65-3.6		2ω=56.8-3.1
R1 =41.972	D1=1.10	N1=1.846660	ν1=23.9
R2 =20.411	D2=4.50	N2=1.696797	ν2=55.5
R3 =593.259	D3=0.15		
R4 =20.927	D4=2.50	N3=1.772499	ν3=49.6
R5 =51.789	D5= Variable		
R6 =19.005	D6=0.70	N4=1.882997	ν4=40.8
R7 =4.996	D7=2.82		
R8 =-14.156	D8=0.60	N5=1.834807	ν5=42.7
R9 =31.325	D9=0.04		
R10=8.379	D10=2.60	N6=1.846660	ν6=23.9
R11=-19.128	D11=0.31		
R12=-9.376	D12=0.60	N7=1.804000	ν7=46.6
R13=20.005	D13=Variable		
R14=Diaphragm	D14=0.70		
*R15=8.451	D15=3.65	N8=1.583126	ν8=59.4

*R16=-23.424	D16=0.15		
R17=11.097	D17=0.70	N9=1.846660	ν9=23.9
R18=7.069	D18=Variable		
R19=12.620	D19=3.00	N10=1.516330	ν10=64.1
R20=-7.111	D20=0.60	N11=1.805181	ν11=25.4
R21=-12.389	D21=2.71		
R22=Infinity	D22=4.00	N12=1.516330	ν12=64.2
R23=Infinity	D23=0.00		
R24=Infinity			

Focal length	3.7	13.87	83.21
Variable separation			
D5	0.70	12.02	19.26
D13	20.36	9.04	1.80
D18	10.17	5.15	11.66

Aspherical coefficients

Fifteenth surface: K=-4.14531e+00

B=7.92437e-04 C=-1.70529e-05 D=3.23520e-07 E=2.95570e-09

Sixteenth surface: K=-2.07521e+01

B=1.71238e-04 C=-8.68267e-06 D=3.41507e-07 E=2.96413e-09

The Second Numerical Example

f=3.60-80.96 Fno=1.65-3.6 2ω=58.1-3.2

R1 =43.270	D1=1.10	N1=1.846660	ν1=23.9
R2 =20.378	D2=4.80	N2=1.696797	ν2=55.5
R3 =1106.334	D3=0.15		
R4 =20.679	D4=2.60	N3=1.772499	ν3=49.6
R5 =51.393	D5= Variable		
R6 =19.780	D6=0.70	N4=1.882997	ν4=40.8
R7 =4.567	D7=2.81		
R8 =-14.203	D8=0.60	N5=1.834807	ν5=42.7
R9 =24.982	D9=0.20		
R10=8.742	D10=2.60	N6=1.846660	ν6=23.9
R11=-13.932	D11=0.23		
R12=-9.428	D12=0.60	N7=1.804000	ν7=46.6
R13=23.567	D13=Variable		
R14=Diaphragm	D14=0.70		
*R15=8.168	D15=3.72	N8=1.583126	ν8=59.4
*R16=-23.701	D16=0.15		
R17=11.589	D17=0.70	N9=1.846660	ν9=23.9
R18=7.067	D18=Variable		
R19=12.208	D19=3.00	N10=1.516330	ν10=64.1
R20=-6.973	D20=0.60	N11=1.805181	ν11=25.4
R21=-12.592	D21=2.71		
R22=Infinity	D22=4.00	N12=1.516330	ν12=64.2
R23=Infinity	D23=0.00		
R24=Infinity			

Focal length	3.60	13.49	80.96
Variable separation			
D5	0.70	12.07	19.34
D13	20.34	8.98	1.71
D18	9.65	4.81	11.19

Aspherical coefficients

Fifteenth surface: K=-5.05661e+00

B=1.05132e-03 C=-3.01859e-05 D=8.62996e-07 E=-1.06064e-08

Sixteenth surface: K=-3.21159e+00

B=3.00621e-04 C=-1.04283e-06 D=5.07044e-07 E=-8.77225e-09

The Third Numerical Example

f=3.60-80.71 Fno=1.65-3.6 2ω=56.8-3.2

R1 =43.059	D1=1.10	N1=1.846660	ν1=23.9
R2 =20.318	D2=4.90	N2=1.696797	ν2=55.5
R3 =1136.271	D3=0.15		
R4 =20.780	D4=2.60	N3=1.772499	ν3=49.6
R5 =52.098	D5= Variable		
R6 =19.891	D6=0.70	N4=1.882997	ν4=40.8
R7 =4.609	D7=2.87		
R8 =-13.845	D8=0.60	N5=1.834807	ν5=42.7
R9 =26.613	D9=0.18		
R10=8.844	D10=2.60	N6=1.846660	ν6=23.9

R11=-13.814	D11=0.21		
R12=-9.521	D12=0.60	N7=1.804000	ν7=46.6
R13=22.786	D13=Variable		
R14=Diaphragm	D14=0.70		
*R15=8.453	D15=3.80	N8=1.583126	ν8=59.4
*R16=-23.391	D16=0.15		
R17=11.324	D17=0.70	N9=1.846660	ν9=23.9
R18=7.102	D18=Variable		
R19=12.394	D19=3.00	N10=1.516330	ν10=64.1
R20=-6.814	D20=0.60	N11=1.805181	ν11=25.4
R21=-12.304	D21=2.71		
R22=Infinity	D22=4.00	N12=1.516330	ν12=64.2
R23=Infinity	D23=0.00		
R24=Infinity			

Focal length	3.60	13.52	80.71
Variable separation			
D5	0.70	12.01	19.24
D13	20.25	8.94	1.71
D18	9.38	4.63	11.08

Aspherical coefficients

Fifteenth surface: K=-6.52138e+00

B=1.21271e-03 C=-4.21180e-05 D=1.11887e-07 E=-1.54763e-08

Sixteenth surface: K=5.27945e+00

B=3.41134e-04 C=-1.34825e-05 D=4.83845e-07 E=-9.25980e-09

Table 1

Numerical Examples	Condition (1)	Condition (2)
	(n12+n13)/2	R21r/ft
First example	1.735	0.060
Second example	1.735	0.056
Third example	1.735	0.057

The present invention thus provides a zoom lens which has high optical performance for its high zoom ratio, and features a compact design with a short overall lens length and a simple construction with a reduced number of lens elements, and provides an optical apparatus incorporating the zoom lens.

While the present invention has been described with reference to what are presently considered to be the preferred embodiments, it is to be understood that the invention is not limited to the disclosed embodiments. On the contrary, the invention is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims. The scope of

the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

WHAT IS CLAIMED IS:

1. A zoom lens comprising, in order from the object end thereof:

a first lens unit having positive refractive power;

a second lens unit having negative refractive power and being movable during zooming, and consisting of four single lenses, separated one from another, three of said four single lenses each having negative refractive power, and one lens having positive refractive power;

a third lens unit, having positive refractive power, comprising at least one lens having positive refractive power and having aspherical surfaces on the two sides thereof; and

a fourth lens unit having positive refractive power and being movable during zooming.

2. A zoom lens according to Claim 1, wherein the first lens unit comprises a first lens having negative refractive power, a second lens having positive refractive power, and a third lens having positive refractive power, and wherein the condition of $1.72 < (n12 + n13)/2 < 1.77$ holds, where n12 represents the index of refraction of the second lens and n13 represents the index of refraction of the third lens.

3. A zoom lens according to Claim 2, wherein the condition of $1.73 < (n12 + n13)/2 < 1.74$ holds.

4. A zoom lens according to Claim 2, wherein the second lens unit comprises, at a position closest to the object, a first lens having negative refractive power, and wherein the condition of $0.04 < R21r/ft < 0.07$ holds, where R21r represents the radius of curvature of the first lens on the image side surface thereof and ft represents the focal length of the entire lens system at the telephoto end.

5. A zoom lens according to Claim 3, wherein the condition of $0.055 < R21r/ft < 0.065$ holds.

6. A zoom lens according to Claim 2, wherein the second lens unit consists of four lenses having negative, negative, positive, and negative refractive power in order from the object end thereof.

7. A zoom lens according to Claim 6, wherein the second lens unit consists of, in order from the object end thereof, a first lens having negative refractive power and having a concave image side surface, a second bi-concave lens having negative refractive power, a third lens having positive refractive power and having a convex object side

surface, and a fourth bi-concave lens having negative refractive power.

8. A zoom lens according to Claim 2, wherein the third lens unit consists of a first bi-convex lens having positive refractive power, and a second meniscus lens having negative refractive power and having a convex object side surface.

9. A zoom lens according to Claim 2, wherein the fourth lens unit consists of two lenses, one having positive refractive power and one having negative refractive power.

10. A zoom lens according to Claim 9, wherein the fourth lens unit comprises a first bi-convex lens having positive refractive power, and a second meniscus lens unit having negative refractive power and having a convex image side surface.

11. An optical apparatus comprising a zoom lens, the zoom lens comprising in order from the object end thereof:

a first lens unit having positive refractive power;

a second lens unit having refractive power and being movable during zooming, and consisting of four single lenses, separated one from another, three of said single lenses each having negative refractive power, and one lens having

positive refractive power;

a third lens unit having positive refractive power comprising at least one lens having positive refractive power and having aspherical surfaces on the two sides thereof; and

a fourth lens unit having positive refractive power and being movable during zooming; and

a body for supporting the zoom lens.

12. An optical apparatus according to Claim 11, wherein the first lens unit comprises a first lens having negative refractive power, a second lens having positive refractive power, and a third lens having positive refractive power, and wherein the condition of $1.72 < (n12 + n13)/2 < 1.77$ holds, where n12 represents the index of refraction of the second lens and n13 represents the index of refraction of the third lens.

ABSTRACT OF THE DISCLOSURE

A zoom lens including, in the order from the object end thereof, a first lens unit having positive refractive power, a second lens unit having negative refractive power and being movable during zooming, and including four single lenses, separated one from another, three of these lenses each having negative refractive power, and one lens element having positive refractive power, a third lens unit, having positive refractive power, including at least one lens having positive refractive power and having aspherical surfaces on the two sides thereof, and a fourth lens unit having positive refractive power and being movable during zooming.

FIG. 1A

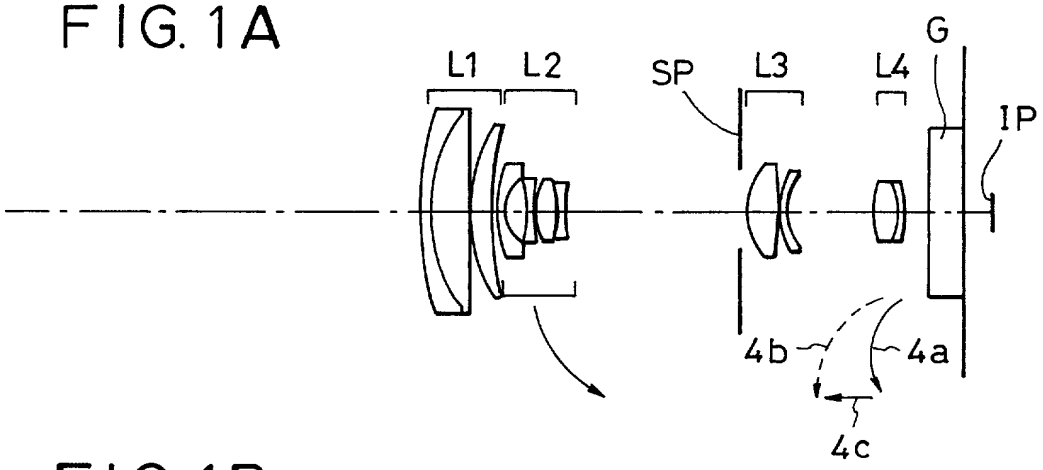

FIG. 1B

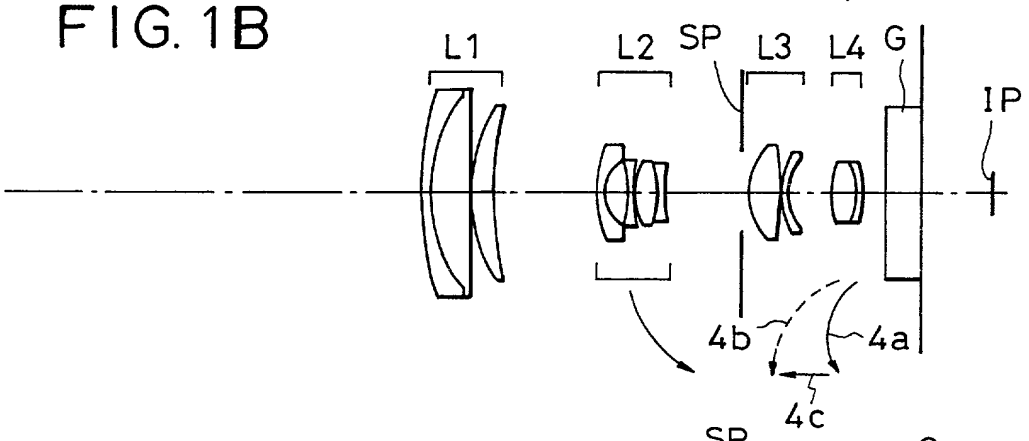

FIG. 1C

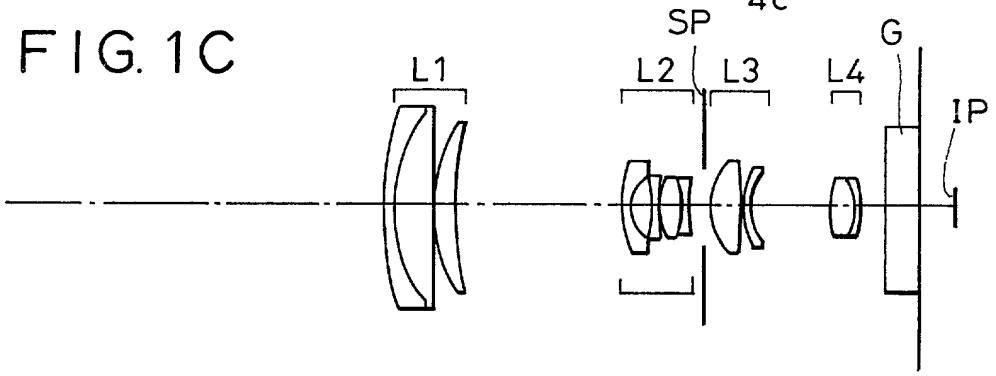

FIG. 2A FIG. 2B FIG. 2C FIG. 2D

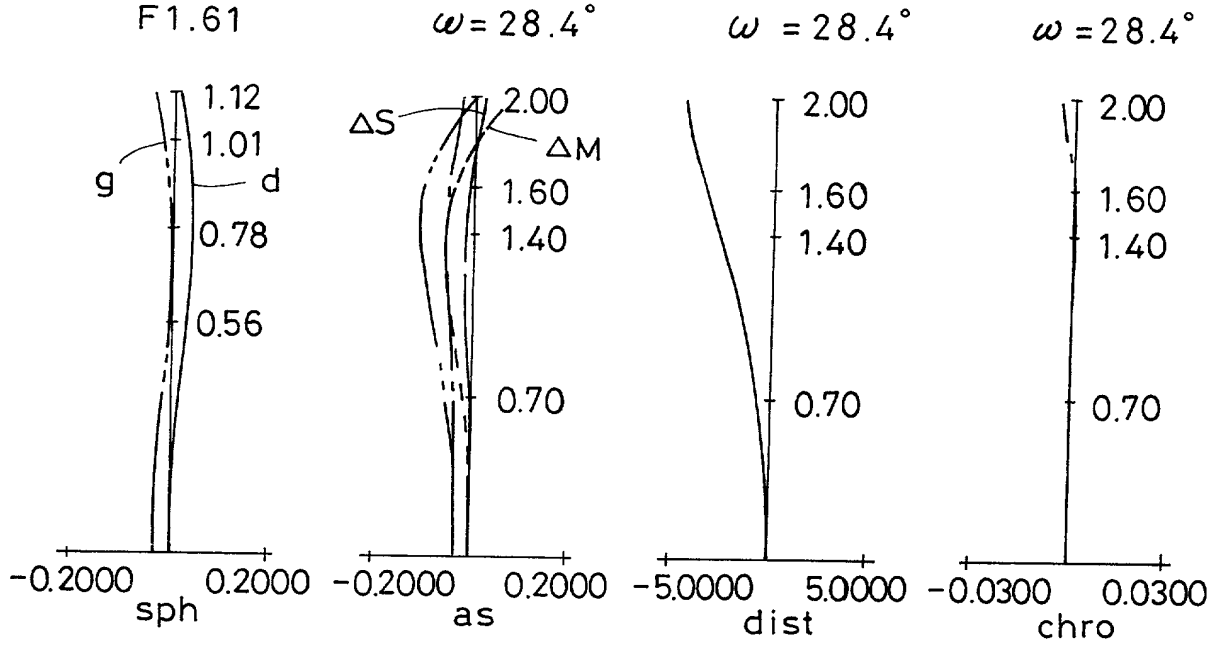

FIG. 2E

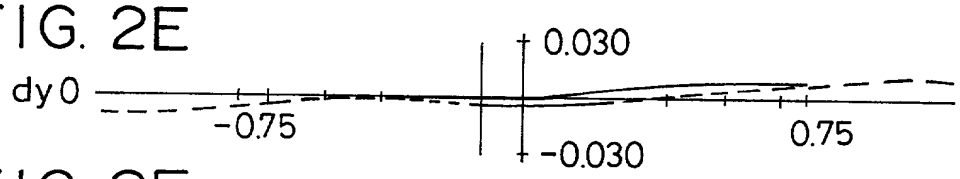

FIG. 2F

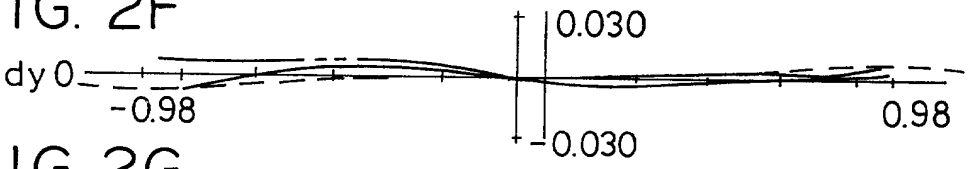

FIG. 2G

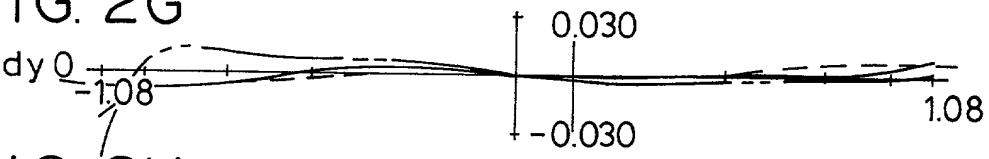

FIG. 2H

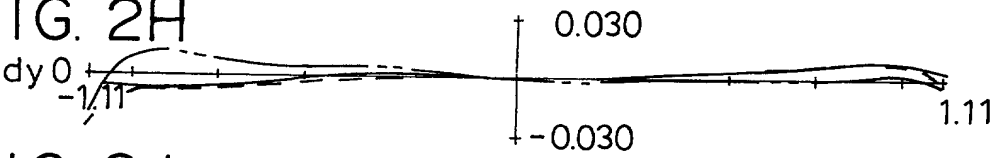

FIG. 2I

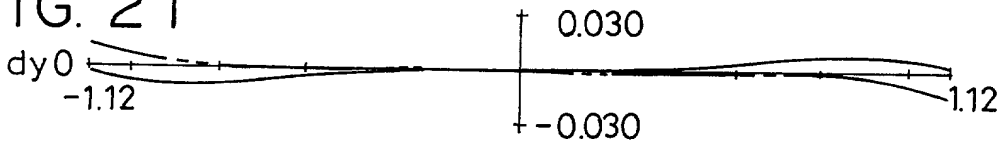

FIG. 3A FIG. 3B FIG. 3C FIG. 3D

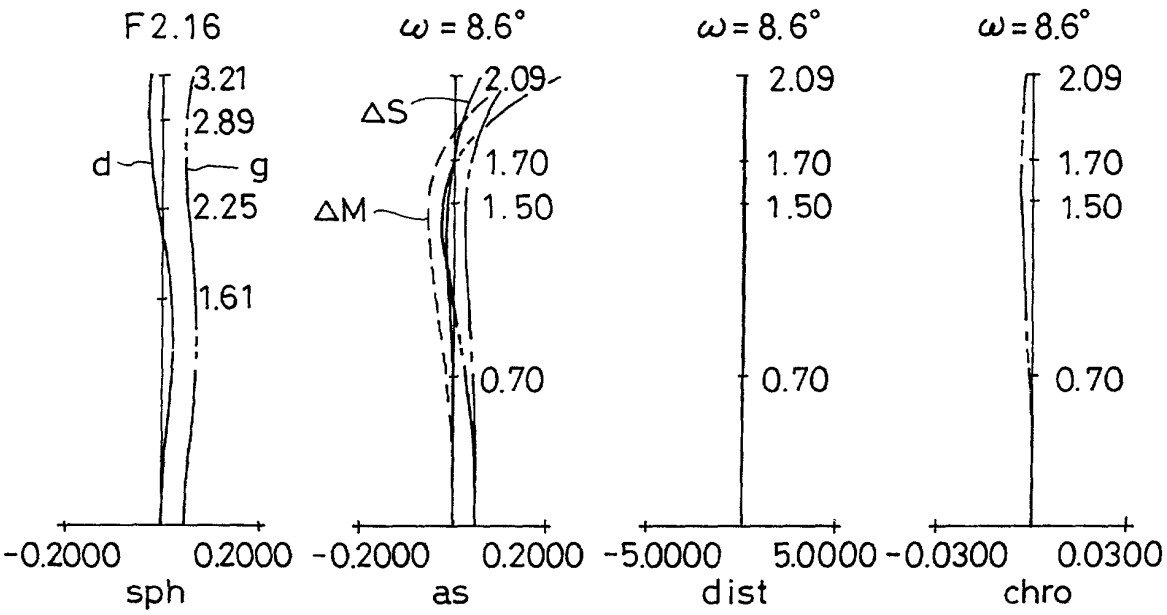

FIG. 3E

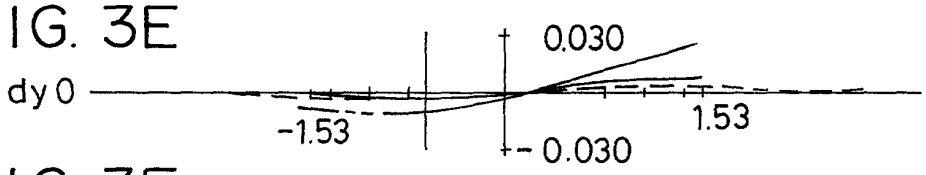

FIG. 3F

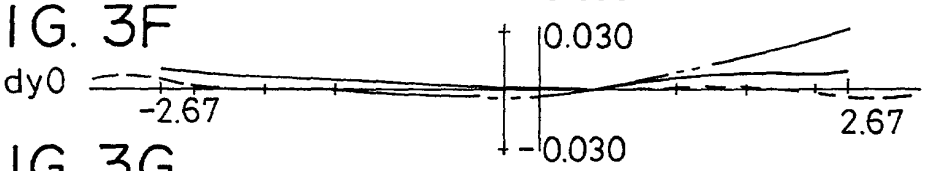

FIG. 3G

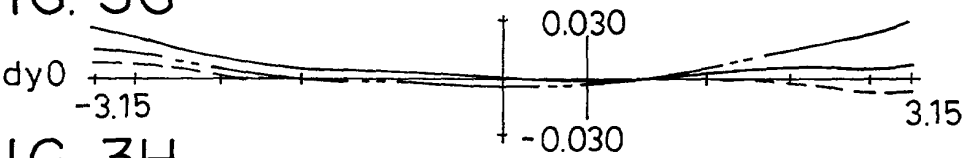

FIG. 3H

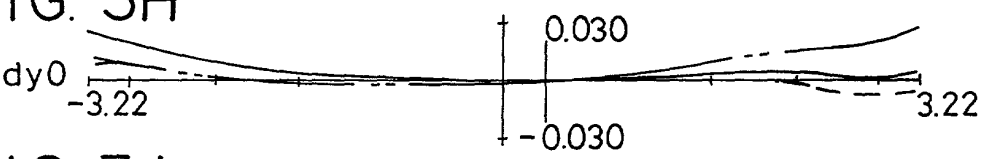

FIG. 3I

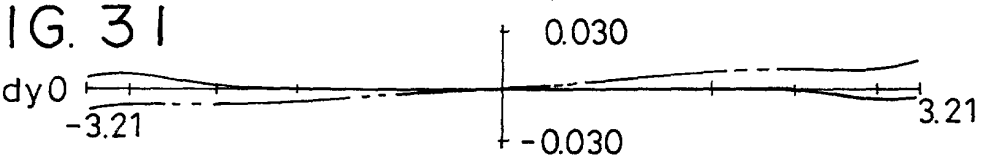

FIG. 4A FIG. 4B FIG. 4C FIG. 4D

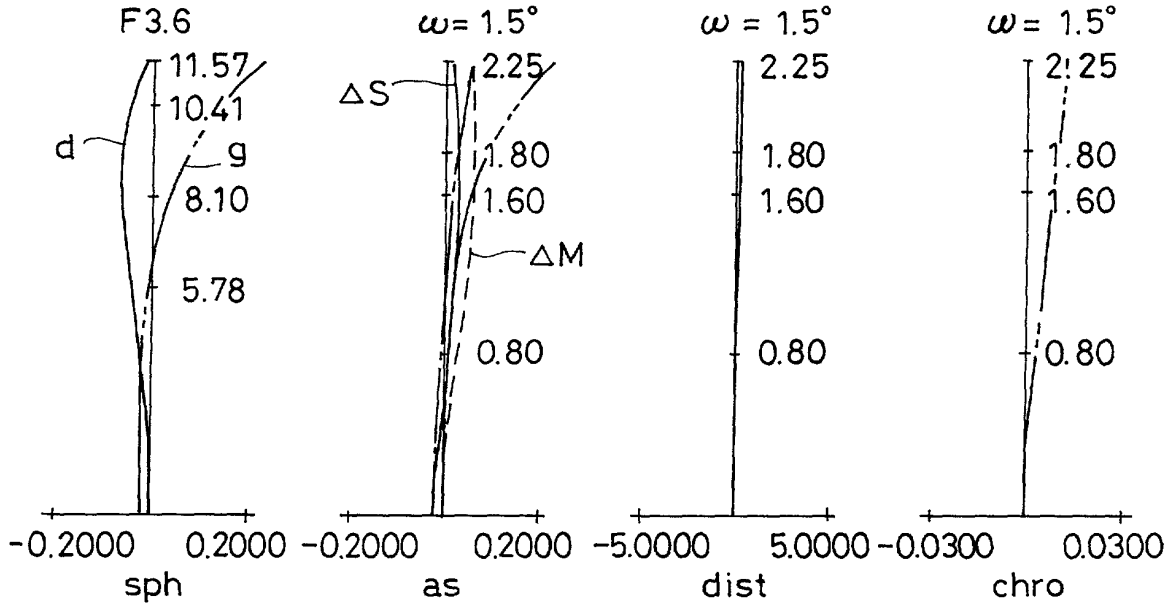

FIG. 4E

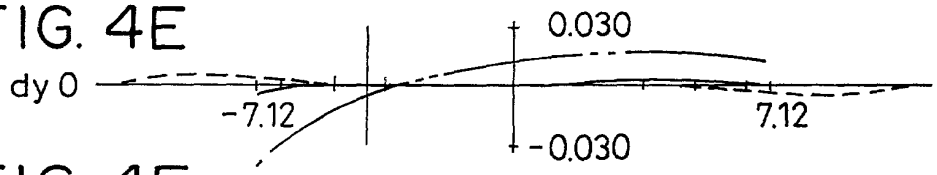

FIG. 4F

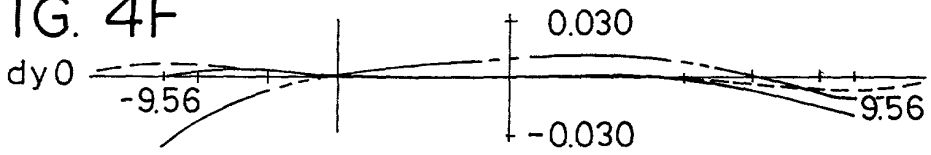

FIG. 4G

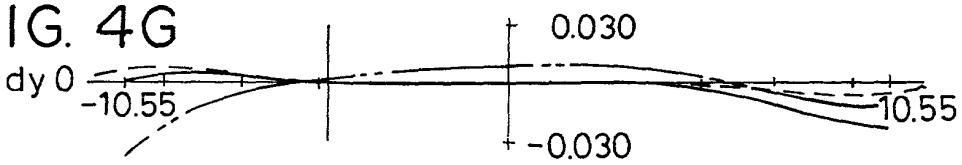

FIG. 4H

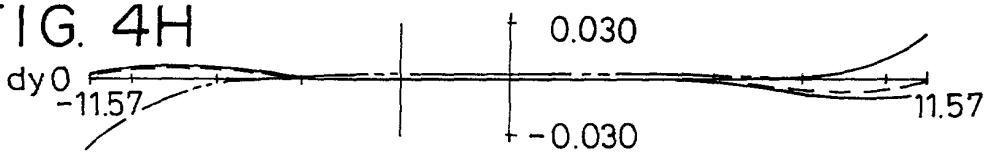

FIG. 4 I

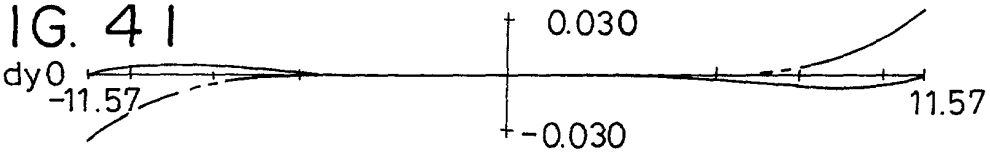

FIG. 5A

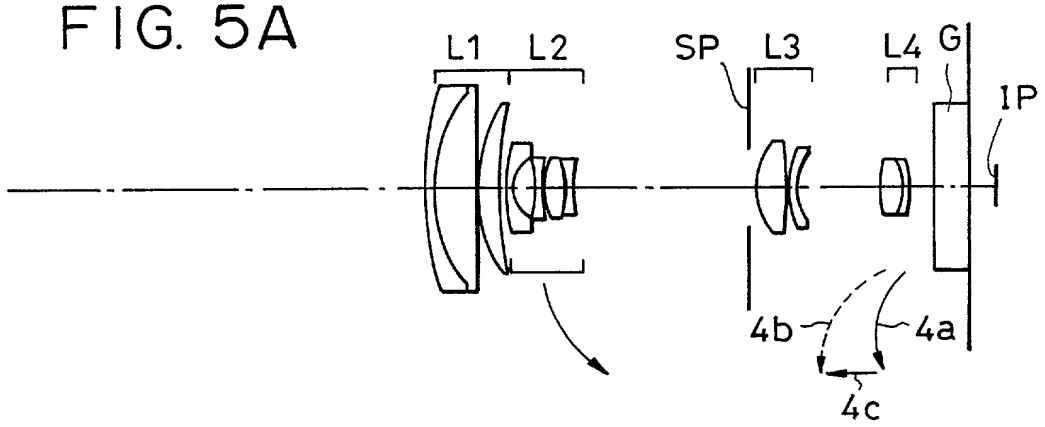

FIG. 5B

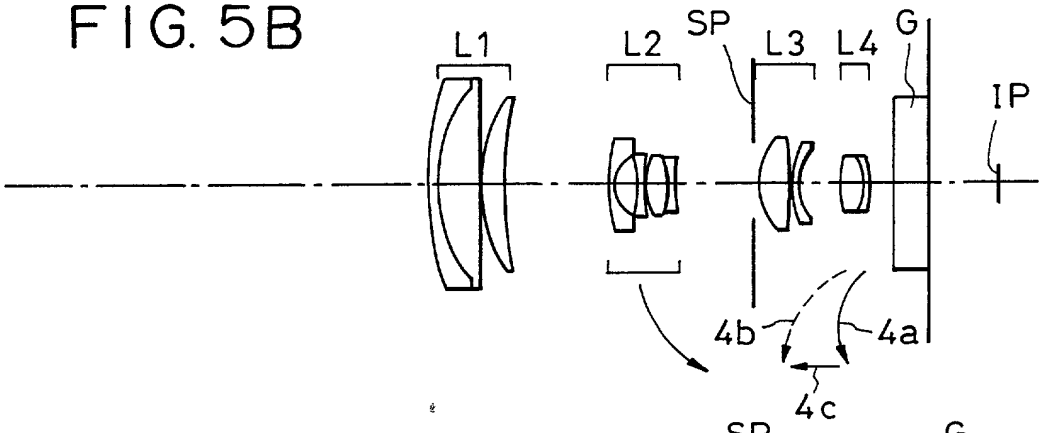

FIG. 5C

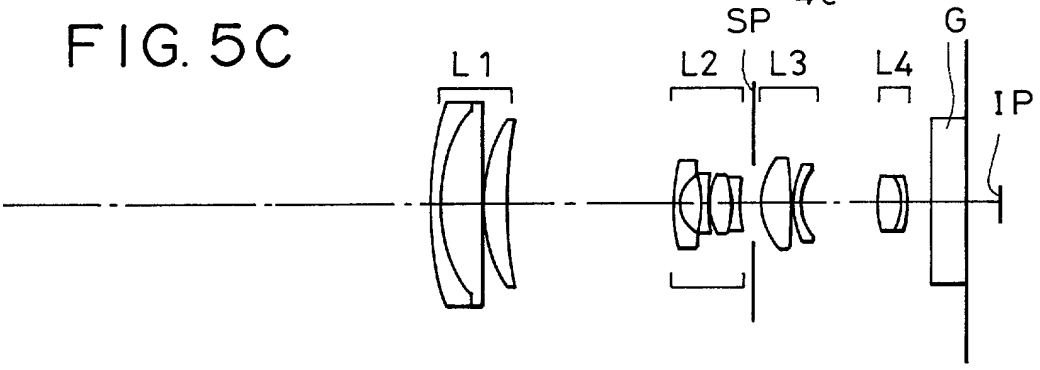

FIG. 6A FIG. 6B FIG. 6C FIG. 6D

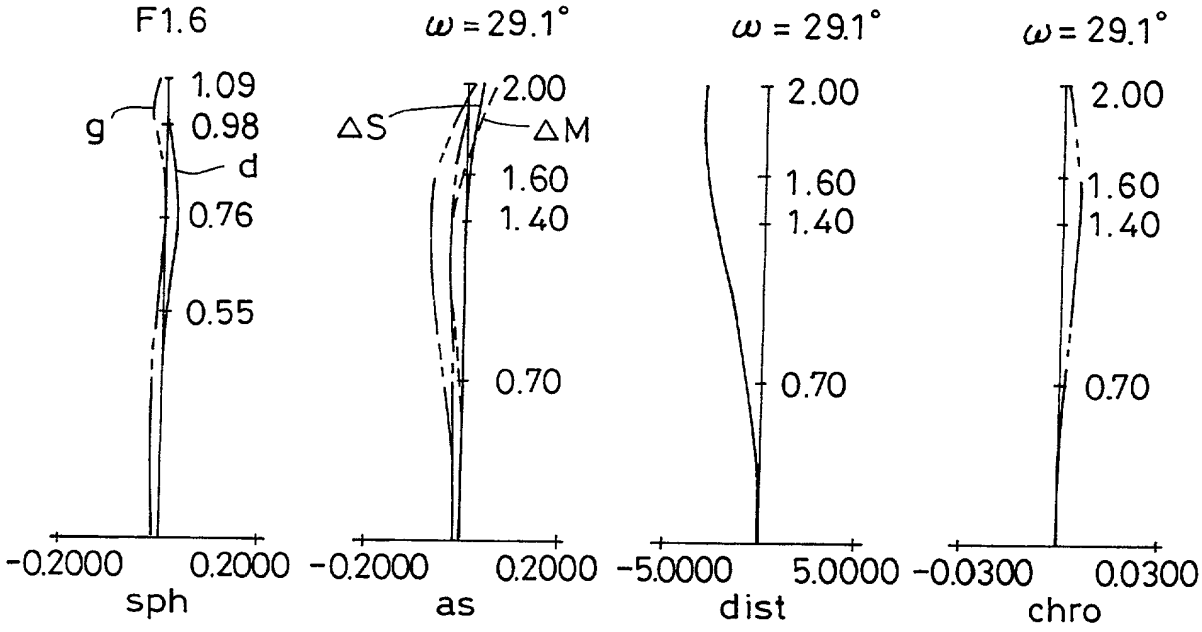

FIG. 6E

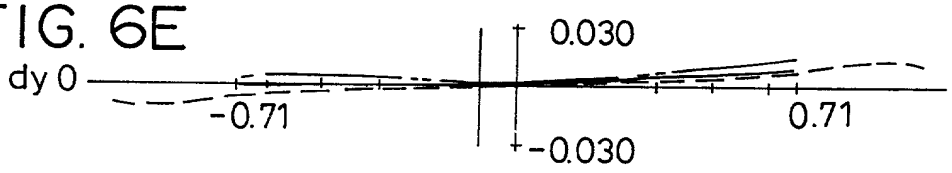

FIG. 6F

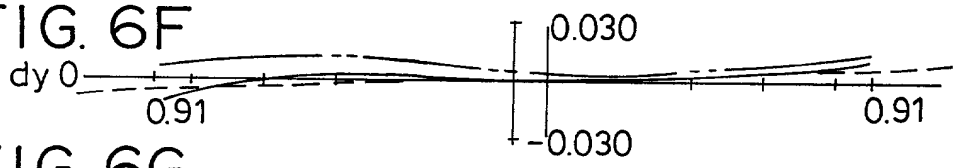

FIG. 6G

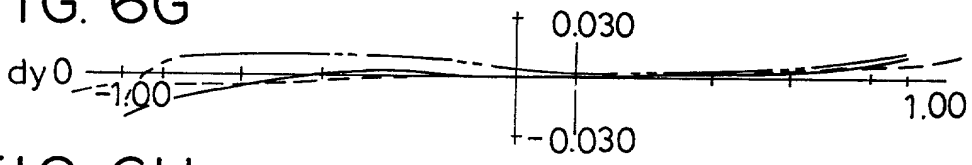

FIG. 6H

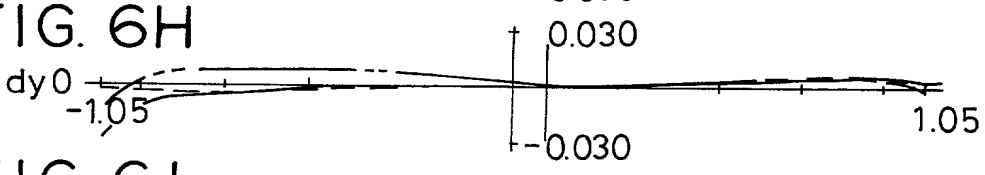

FIG. 6I

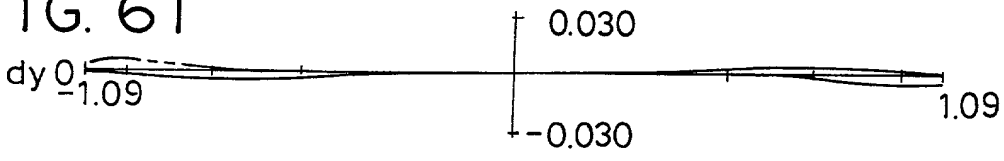

FIG. 7A FIG. 7B FIG. 7C FIG. 7D

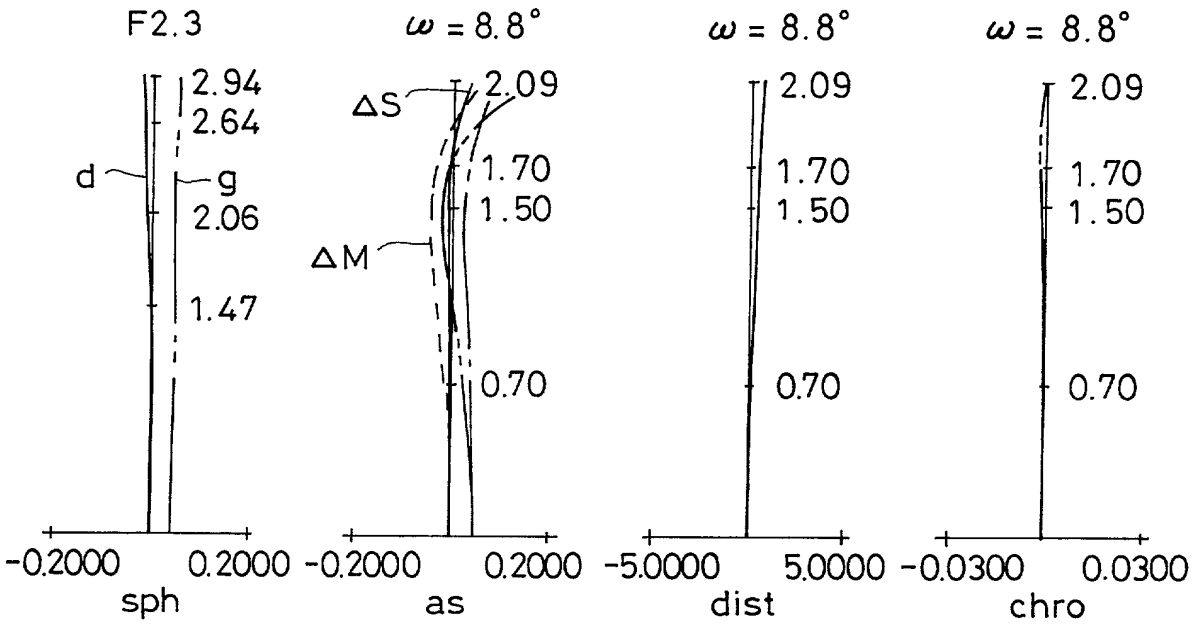

FIG. 7E

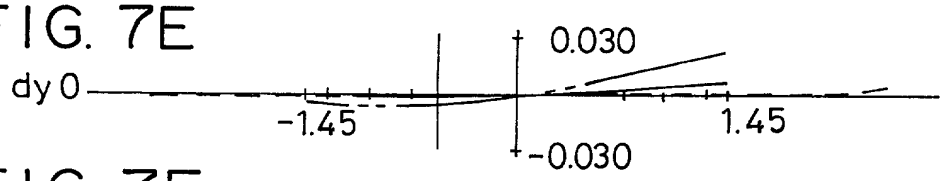

FIG. 7F

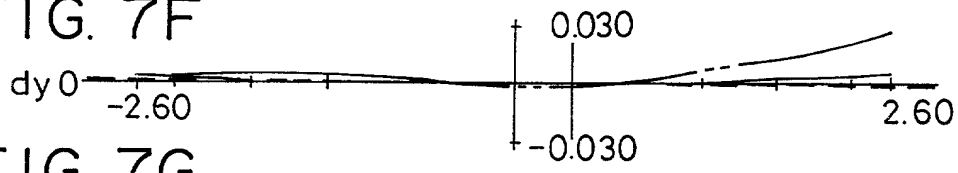

FIG. 7G

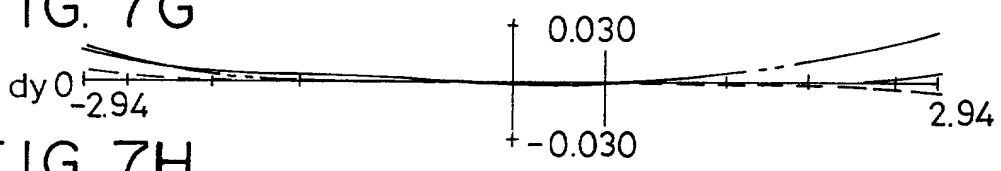

FIG. 7H

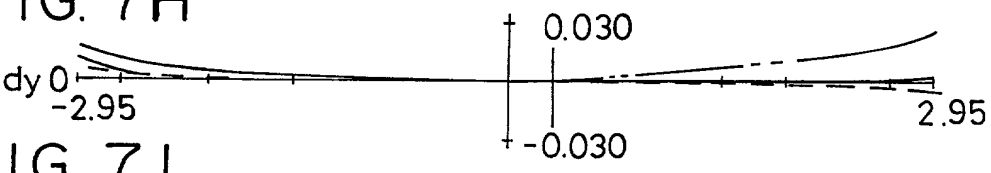

FIG. 7I

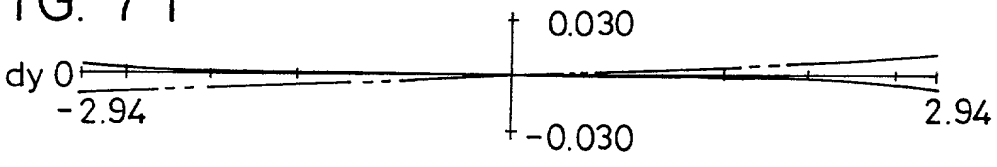

FIG. 8A FIG. 8B FIG. 8C FIG. 8D

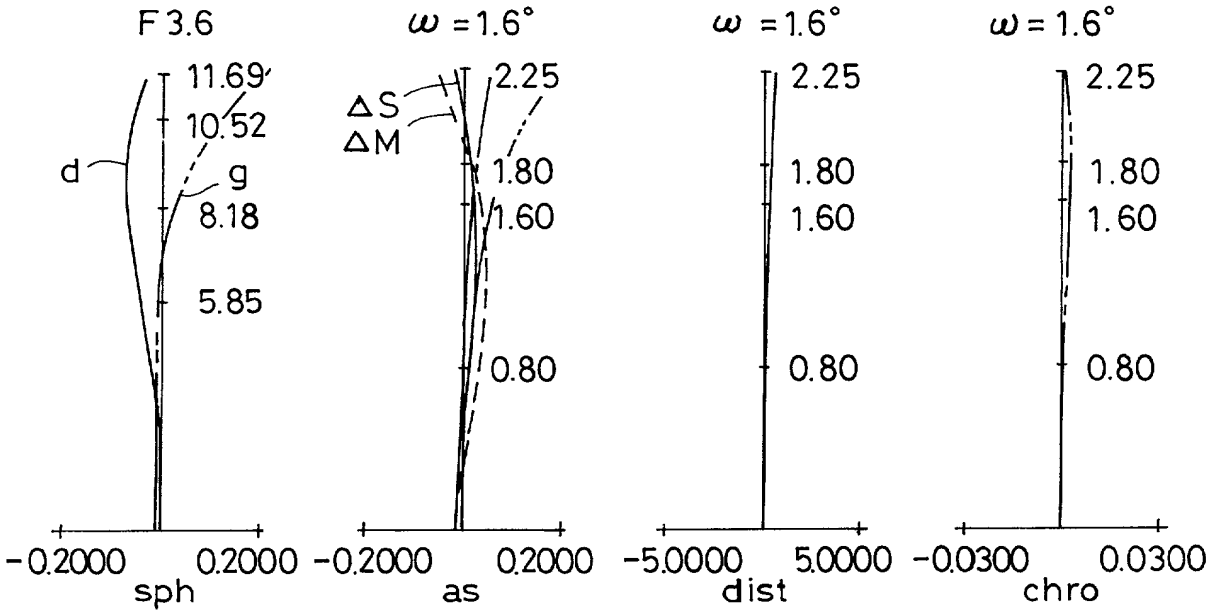

FIG. 8E

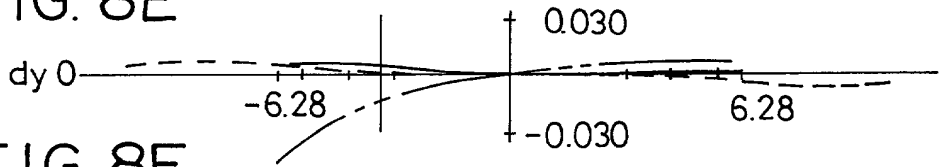

FIG. 8F

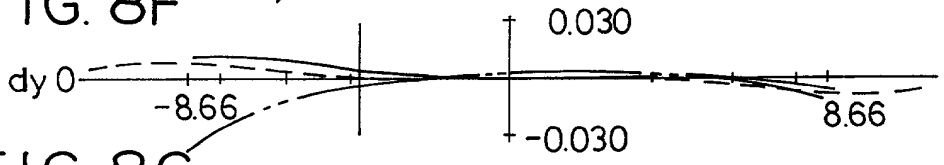

FIG. 8G

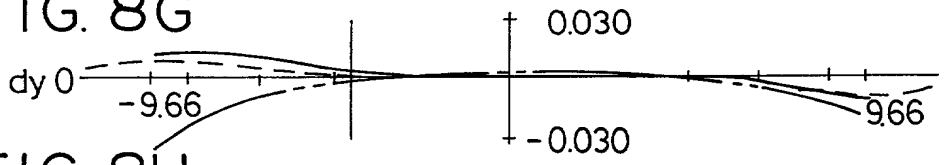

FIG. 8H

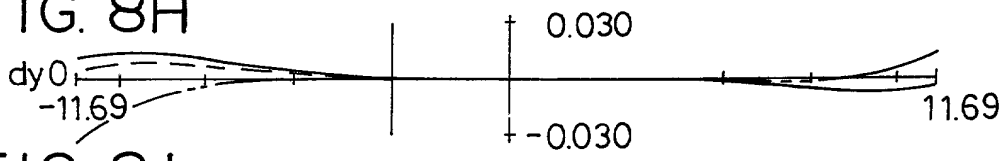

FIG. 8I

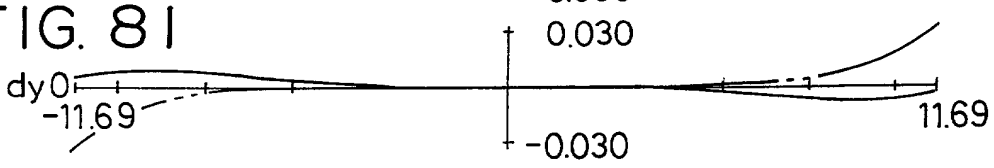

FIG. 9A

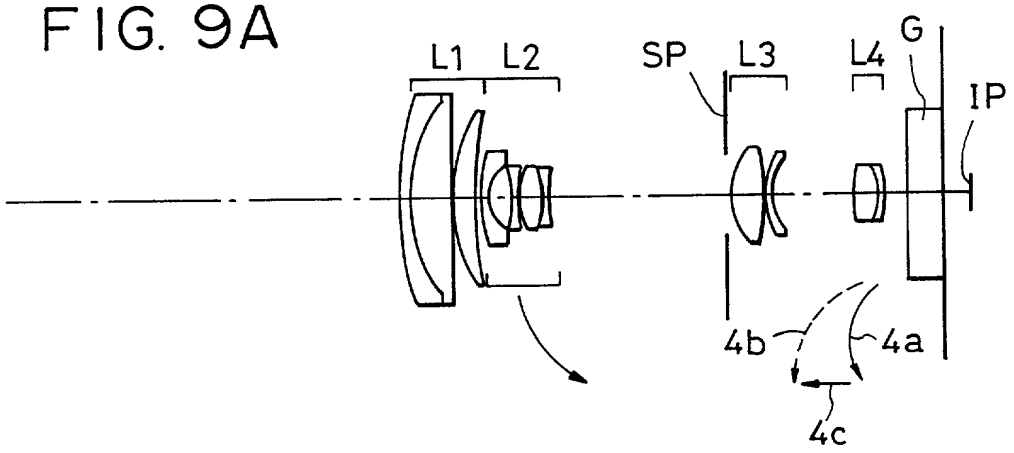

FIG. 9B

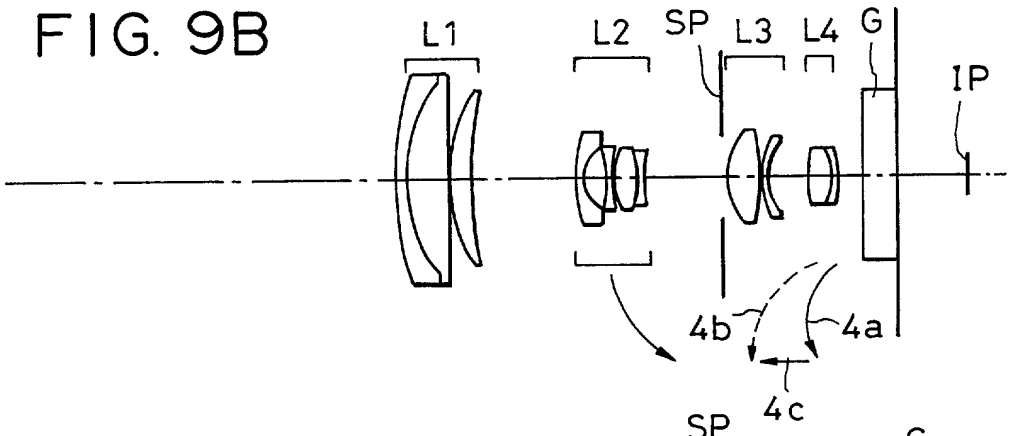

FIG. 9C

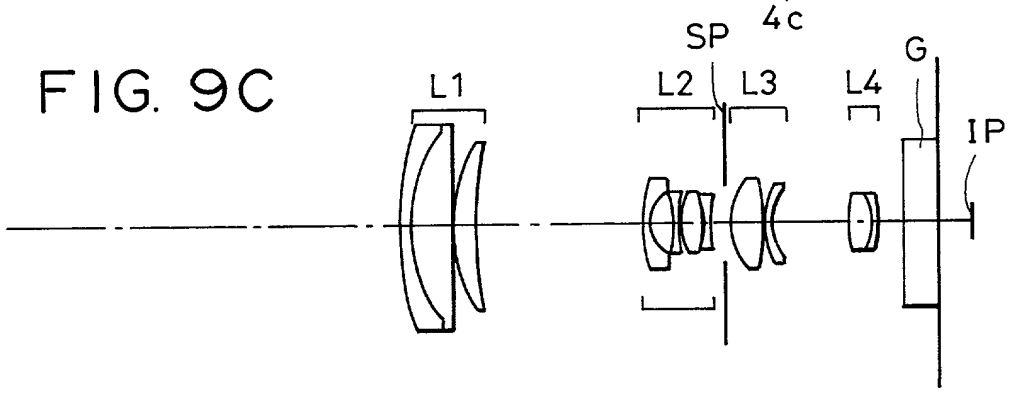

FIG. 10A FIG. 10B FIG. 10C FIG. 10D

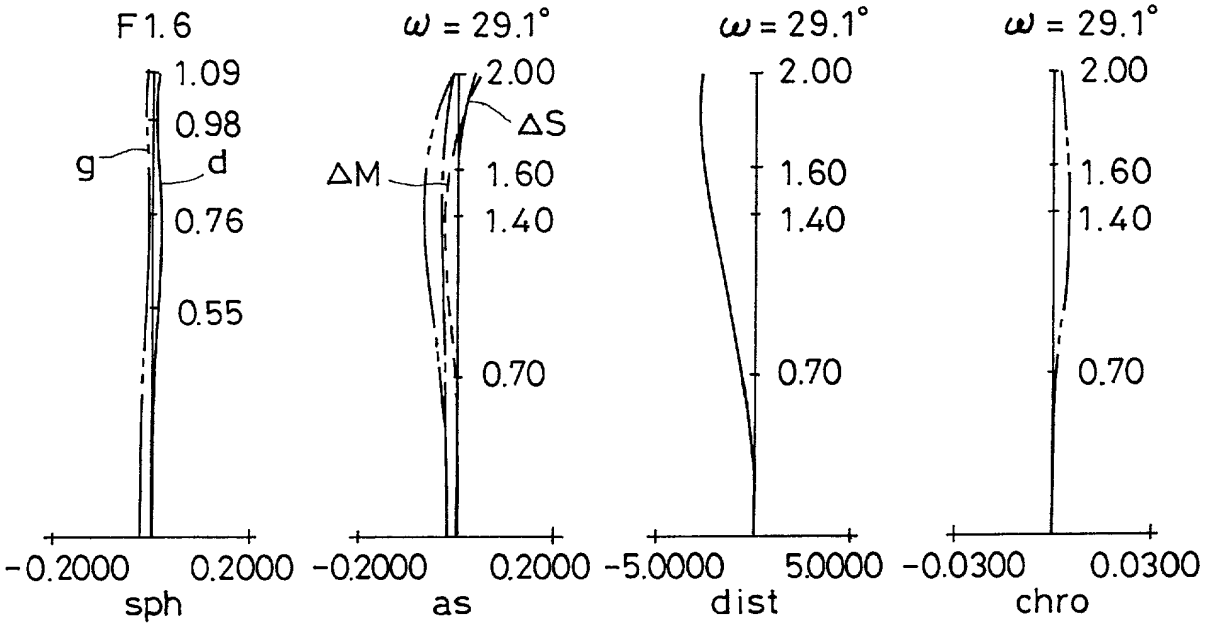

FIG. 10E

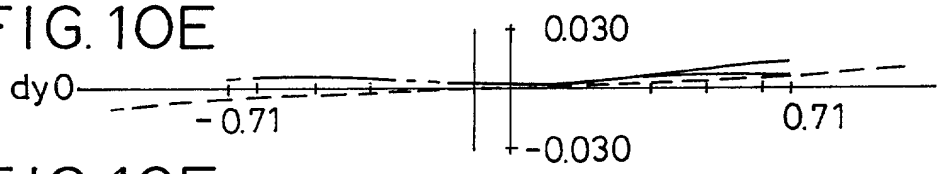

FIG. 10F

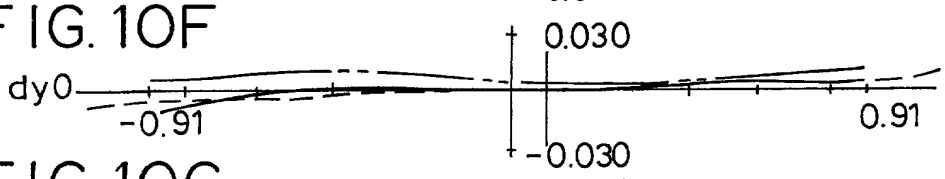

FIG. 10G

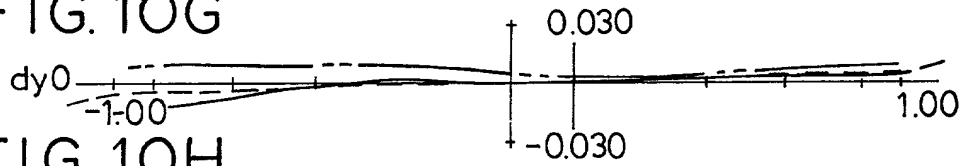

FIG. 10H

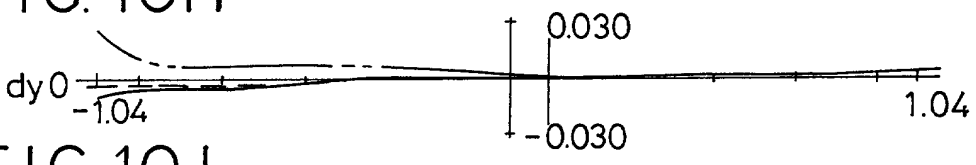

FIG. 10I

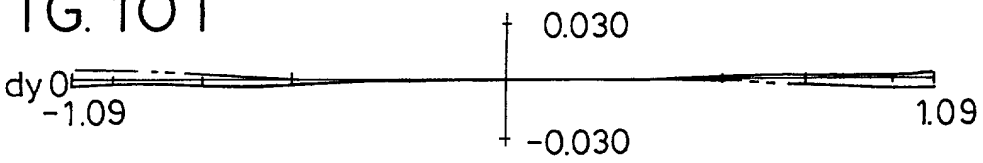

FIG. 11A FIG. 11B FIG. 11C FIG. 11D

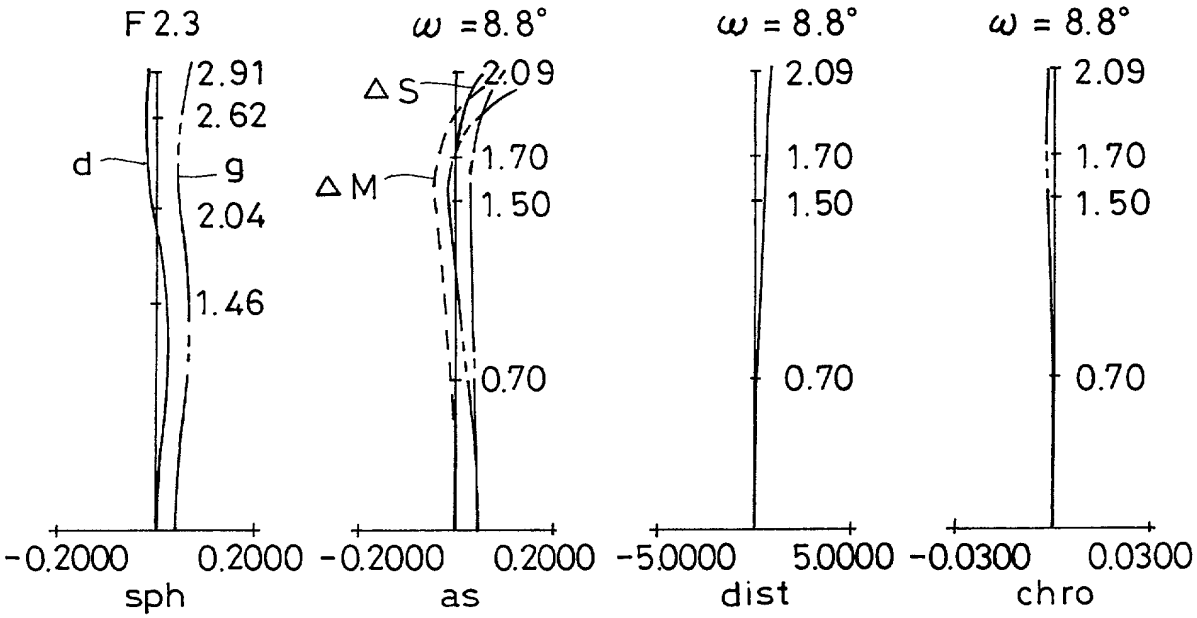

FIG. 11E

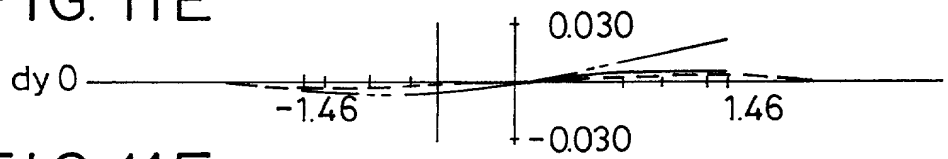

FIG. 11F

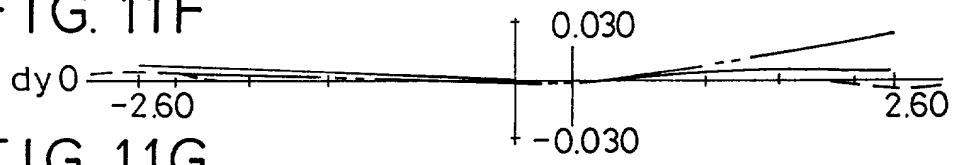

FIG. 11G

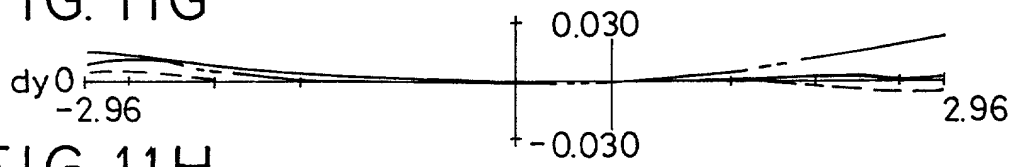

FIG. 11H

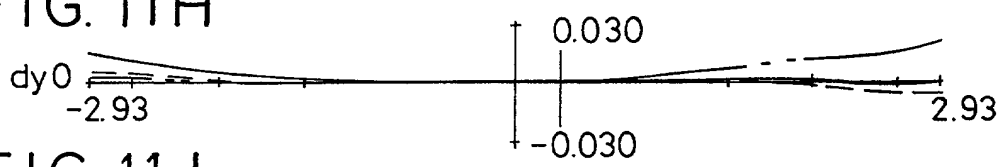

FIG. 11 I

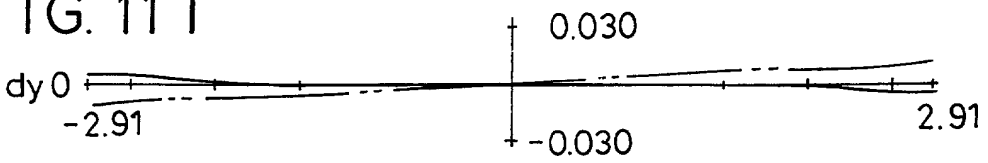

FIG. 12A FIG. 12B FIG. 12C FIG. 12D

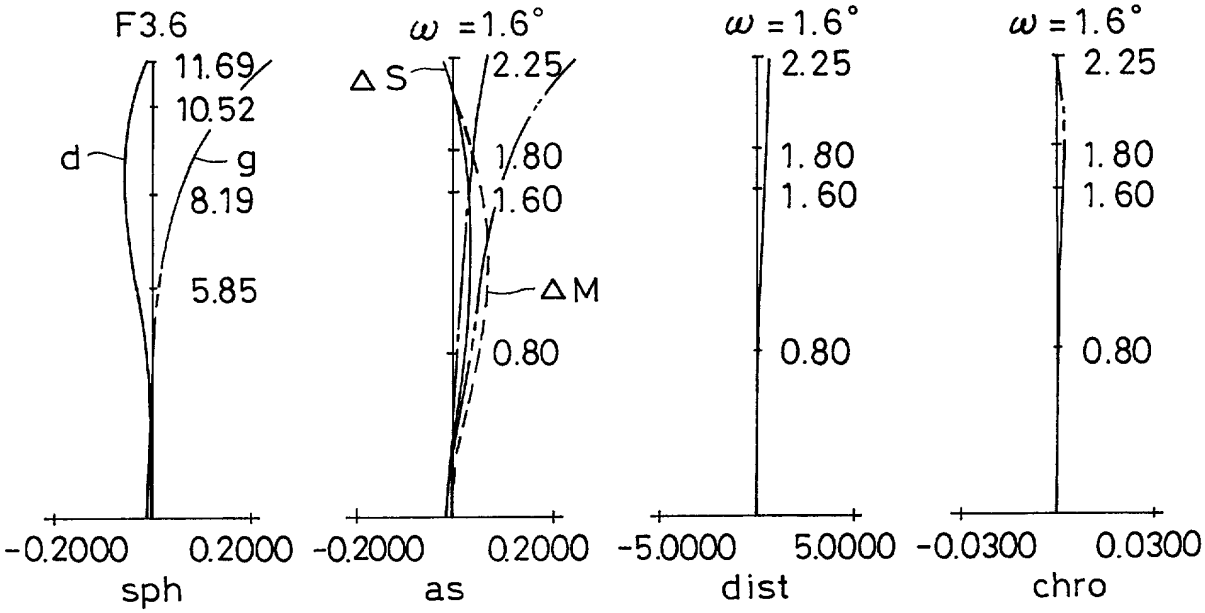

FIG. 12E

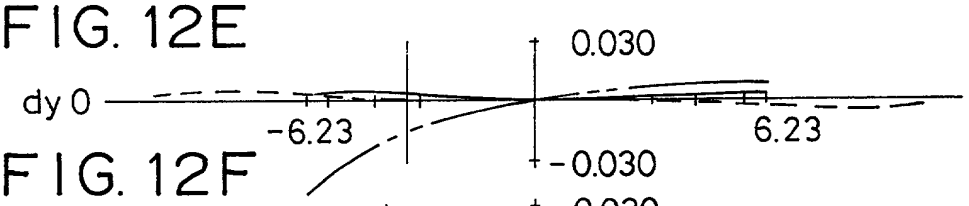

FIG. 12F

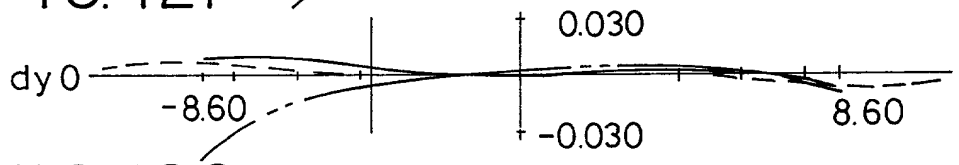

FIG. 12G

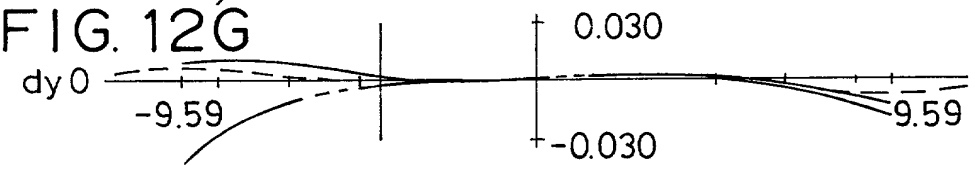

FIG. 12H

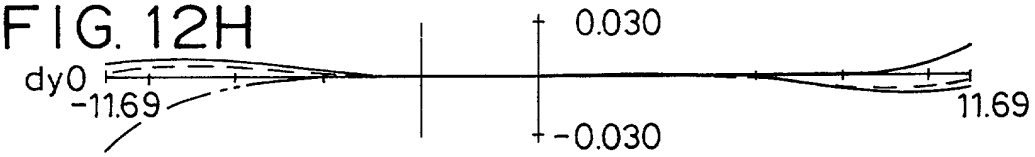

FIG. 12I

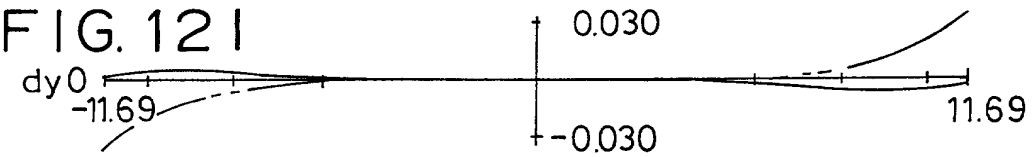
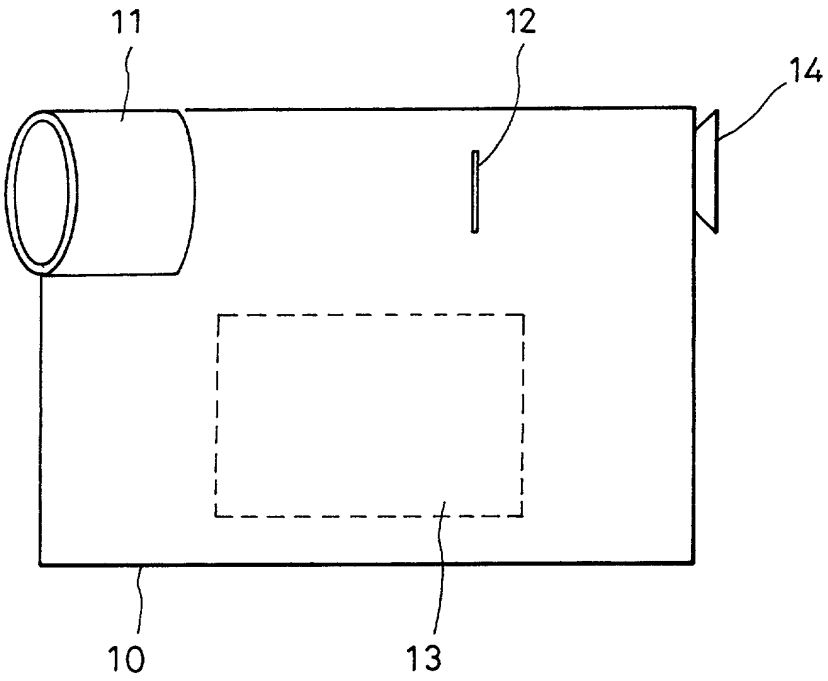
FIG. 13